Development of a Unified SHOC-EDMF PBL Parameterization in the NASA GEOS Model

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SHOC and EDMF background

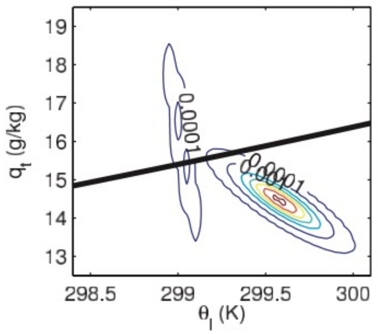
Simplified HOC (Bogenschutz & Krueger 2013)

- Diagnoses higher order moments
- Analytic double gaussian for joint w, th, qt provides buoyancy flux to prognose TKE
- All fluxes downgradient

$$\overline{w'\theta_l'} = -K_H \frac{\partial \overline{\theta_l}}{\partial z}$$

$$\overline{\theta_l'^2} = \tau_v K_H \frac{\partial \overline{\theta_l}}{\partial z} \frac{\partial \overline{\theta_l}}{\partial z}$$

ADG PDF



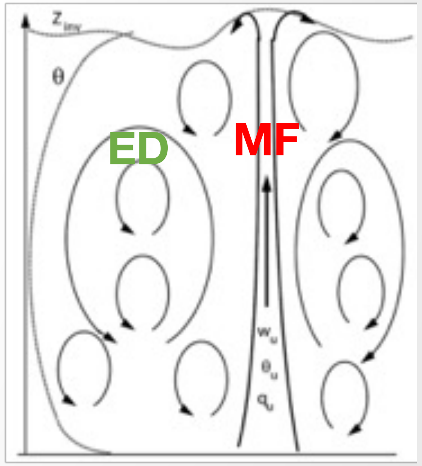
$$\frac{\partial e}{\partial t} = -\frac{\partial}{\partial z}\overline{w'e'} - w\frac{\partial e}{\partial z} + \frac{g}{\theta_v}\overline{w'\theta_v'} - \epsilon_e$$

Eddy Diffusivity - Mass Flux

(JPL version, Suselj et al 2021)

$$\overline{w'\phi'} \approx \underbrace{-K\frac{\partial \overline{\phi}}{\partial z}}_{\text{ED}} + \underbrace{\sum_i M_i(\phi_{ui} - \overline{\phi})}_{\text{MF}}$$

- Small eddy transport represented by diffusion;
- Nonlocal updraft transport by mass flux;
- JPL: multi-plume with stochastic entrainment



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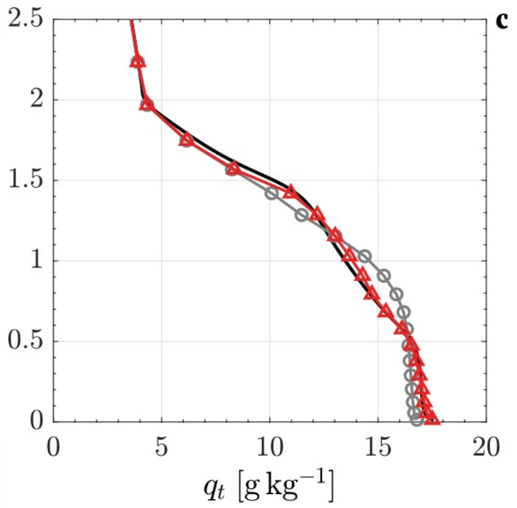
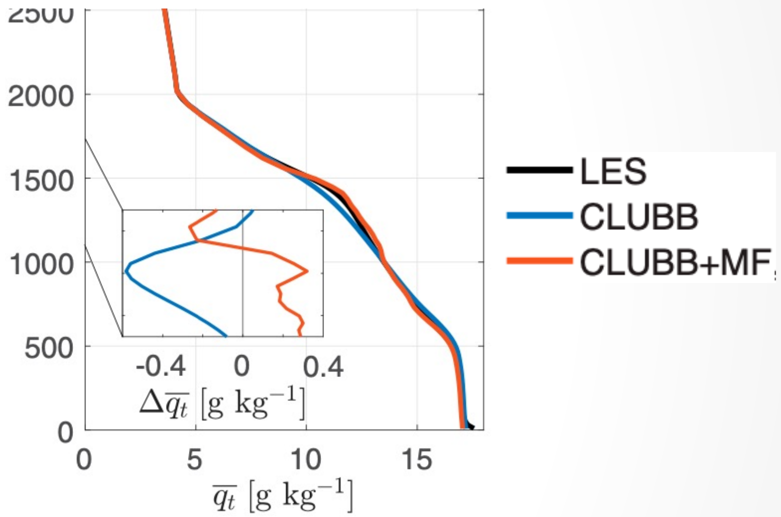
Recent work has combined EDMF and HOC approaches

Chinita et. al., 2022:
SHOC+MF in DoE SCREAM



Witte et. al., 2022:
CLUBB+MF in NCAR CESM



Improved profiles when MF tendencies included, vs. SHOC/CLUBB alone.

No direct contribution from MF to higher order moments.

SHOC-MF in the NASA GEOS model

Our implementation is unique in that we include Mass Flux contributions to all HOM calculations:

$$\overline{w'\theta_l'} = -K_H \frac{\partial \overline{\theta_l}}{\partial z} + \underbrace{M_u(\theta_{lu} - \overline{\theta_l})}_{\textbf{MF}}$$

$$\overline{\theta_l'^2} = \tau_v \left[K_H \frac{\partial \overline{\theta_l}}{\partial z} - \underbrace{M_u(\theta_{lu} - \overline{\theta_l})}_{\textbf{MF}} \right] \frac{\partial \overline{\theta_l}}{\partial z}$$

This allows ADG PDF to represent entire subgrid area **including updrafts**.

Unified cloud treatment.

$\overline{w'^3}$, $\overline{\theta_l'^3}$, $\overline{q_t'^3}$ are diagnosed directly from MF updrafts.

"Classic" SHOC estimates third moments following Canuto et al., 2001.

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Our methodology

SHOC+MF implemented in NASA GEOS model

- GCM used for NWP (12km), S2S (50km), reanalysis (25km), GCRM (3km)
- Testing in SCM:
  - ARM97 continental diurnal CBL (Brown et al 2002)
  - BOMEX trade cumulus (Siebesma et al 2003)
  - DYCOMS II-RF01 Nocturnal non-precipitating stratocumulus (Zhu et al 2005)
  - Other cases (not shown)
  - dz=25m, dt=225s

Comparing with LES:

- System for Atmospheric Modeling (SAM v6.11.8)
- ARM/BOMEX: dx/y=50m, dz=40m, 12x12 km
- DYCOMS: dx/y=25m, dz=5m, 6.4x6.4 km

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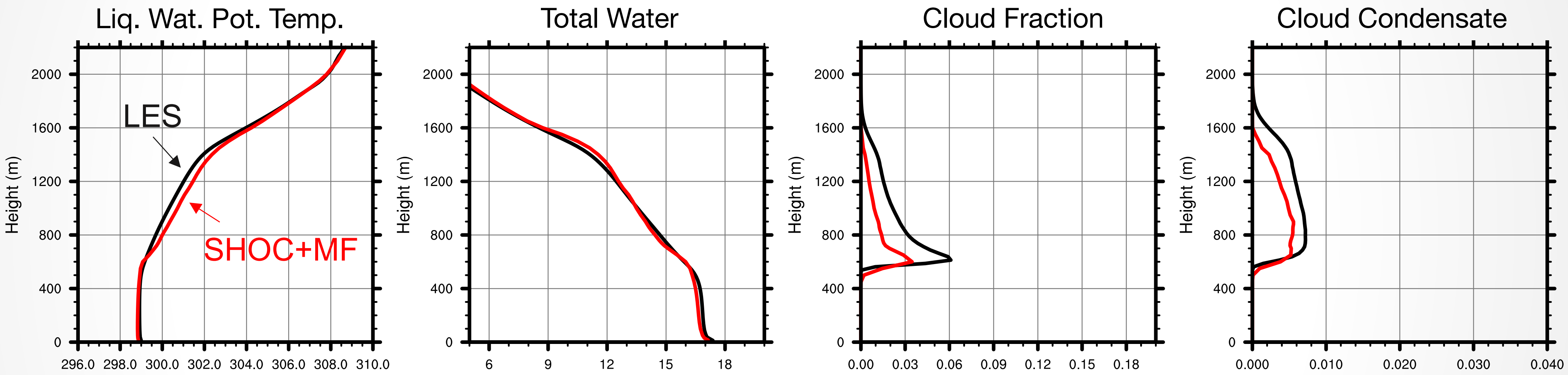
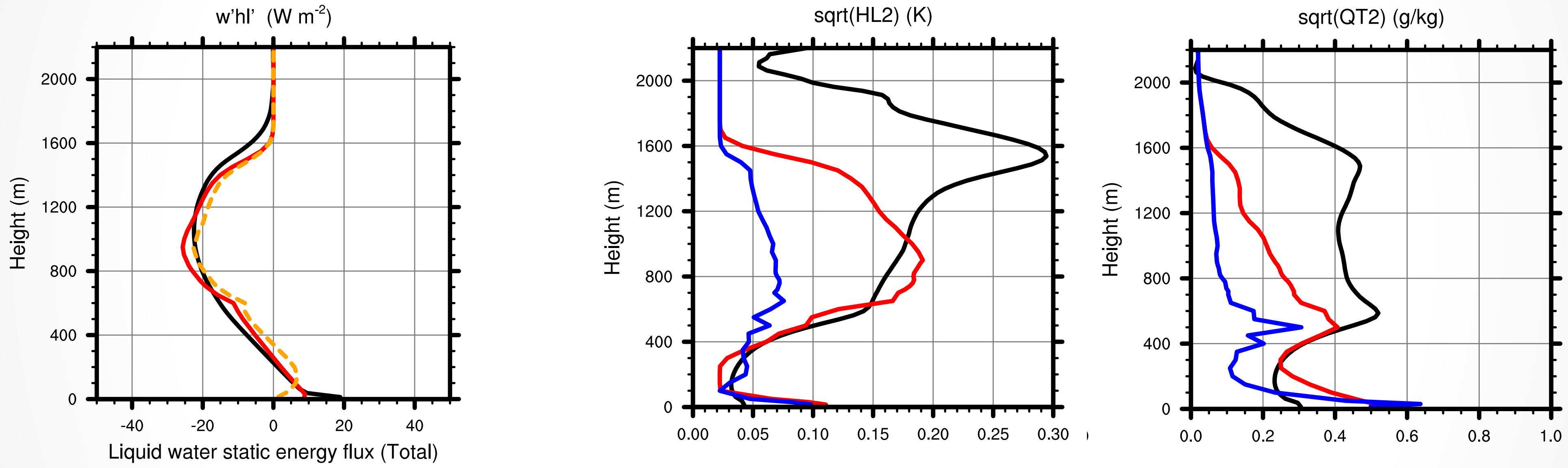
BOMEX mean profiles



Good agreement in θ_l, q_t. Cloud too few, too shallow.

Variances underestimated when MF contribution not included

BOMEX:



W'hl' dominated by MF in cloud layer

Without MF contribution, variances are underestimated

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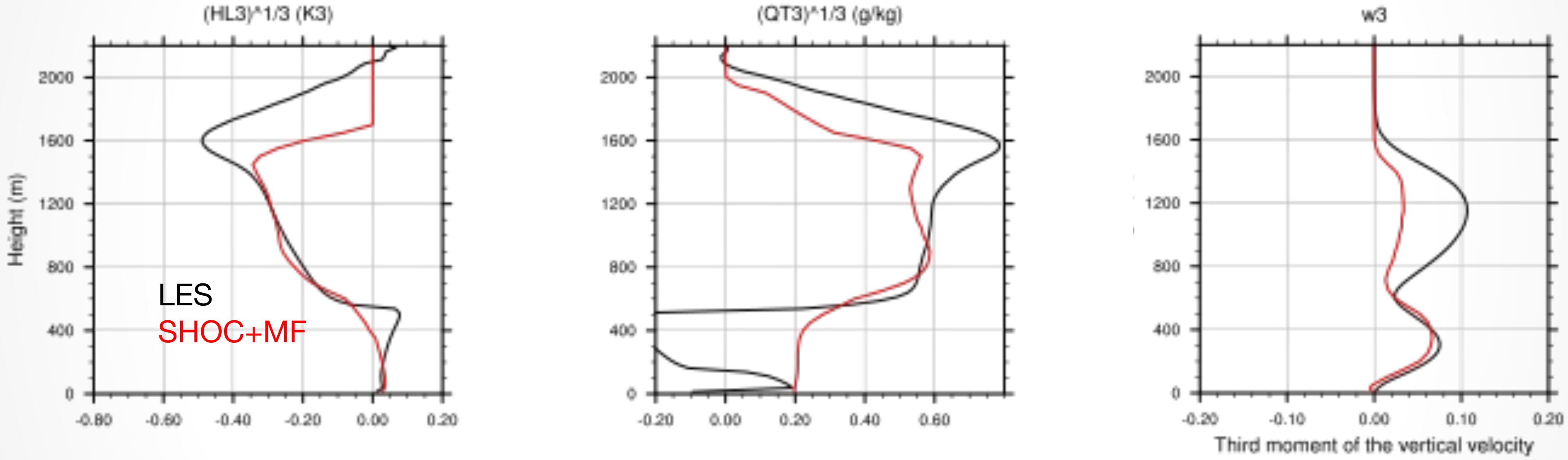
Third moments diagnosed from MF

BOMEX:



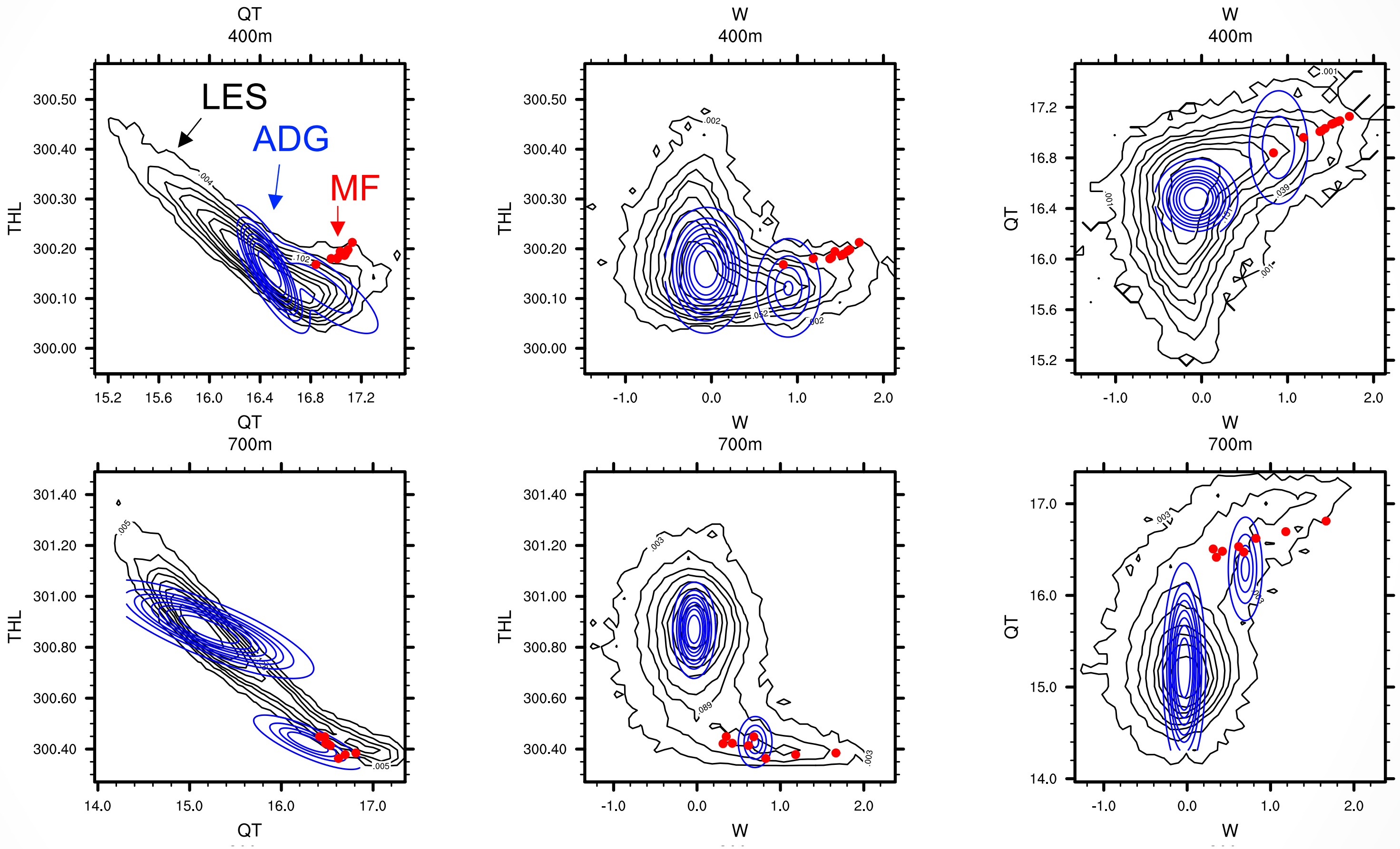
Mass flux qualitatively captures third moments, with some discrepancies

SHOC-MF ADG joint PDFs compared with MF, LES

BOMEX:

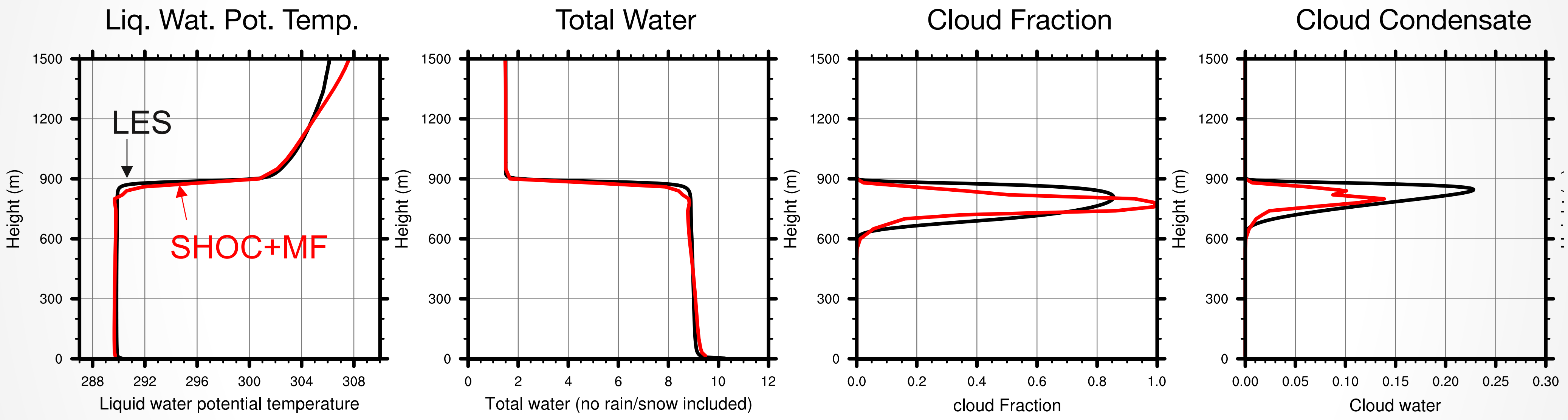
z=400m

z=700m



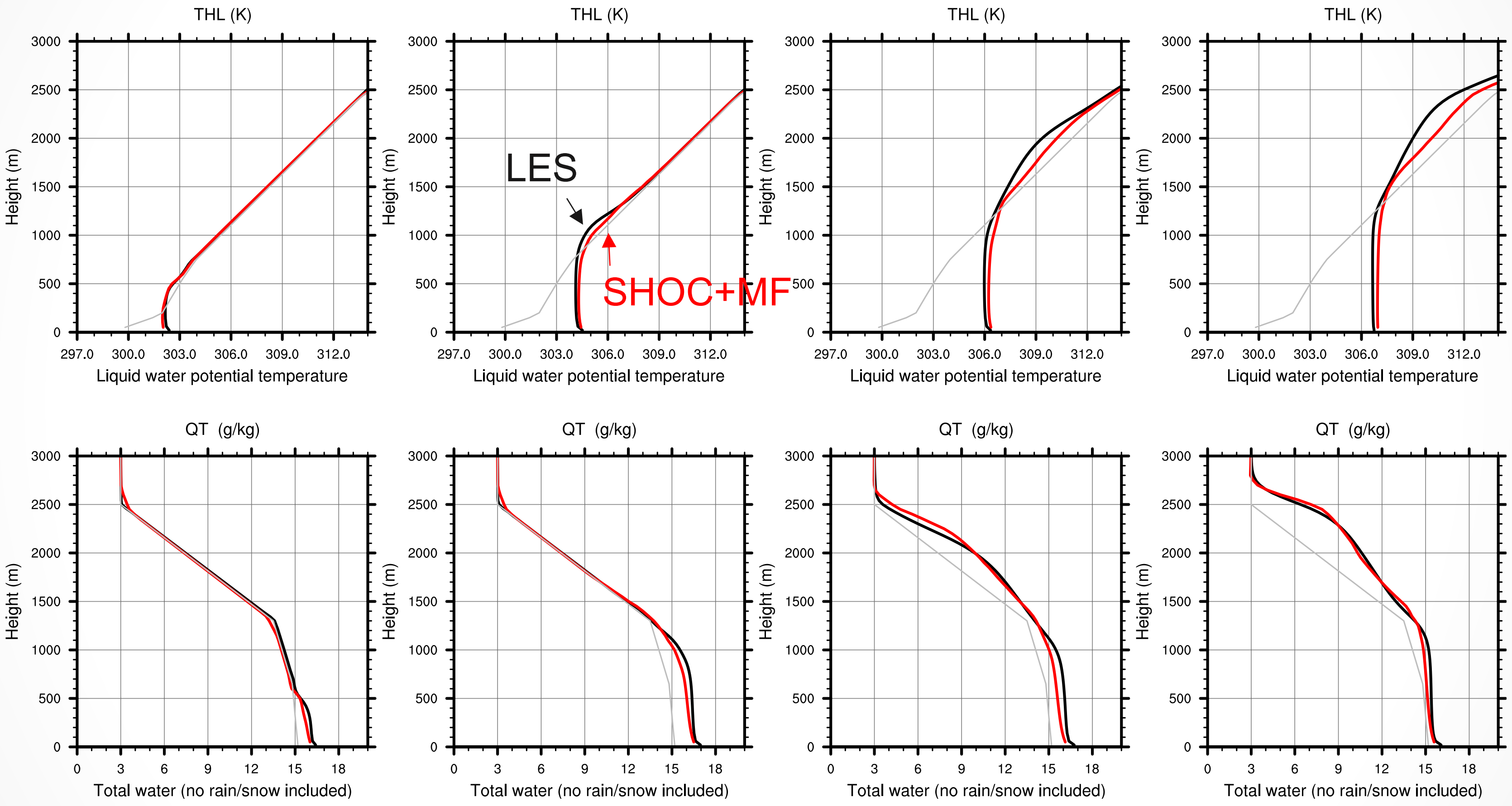
Reasonable agreement between ADG PDF plume 1 and MF properties, and with LES.

DYCOMS II-RF01 mean profiles



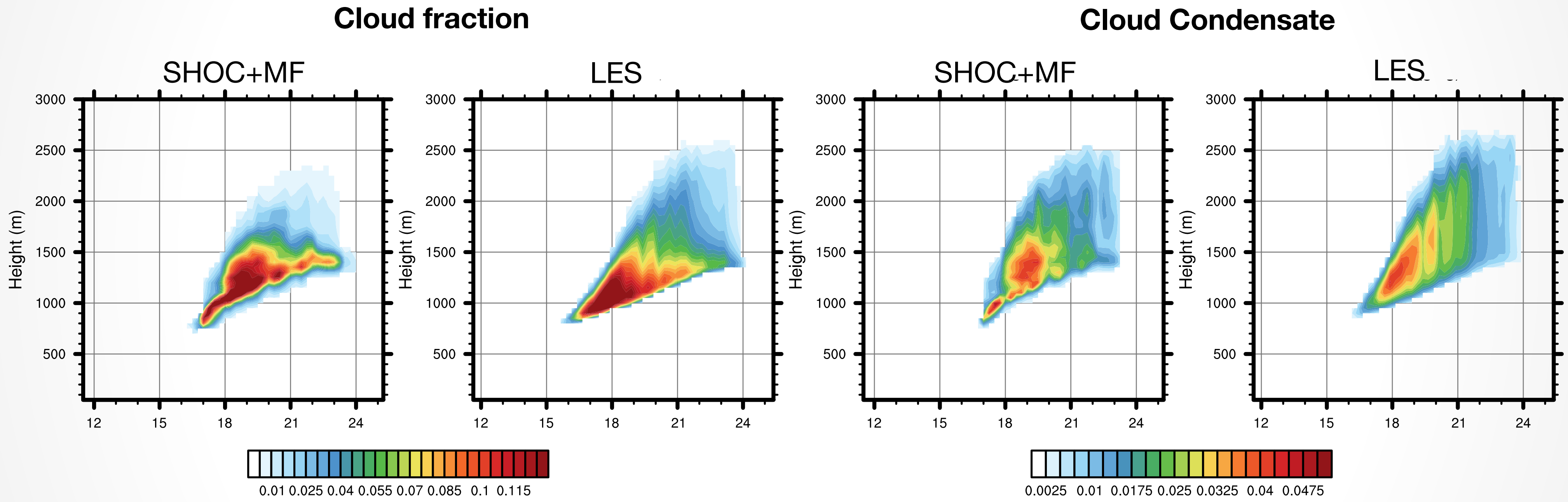
Good agreement in θ_l, q_t, mixed layer depth. Condensate somewhat underestimated.

ARM SGP mean profiles



SHOC-MF captures the diurnal evolution of θ_l and $w'\theta_l'$

ARM SGP cloud evolution vs. LES



Good agreement in timing, cloud base, fraction and condensate. Cloud top too shallow.

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Conclusions

- We have implemented a SHOC+MF parameterization in the NASA GEOS model;
- The approach is unique in that MF contributions are included in higher order moments determining the double-gaussian PDF;
- Including MF contributions yields more realistic (vs LES) HOMs compared with the SHOC-only approach, and allows the PDF to represent the updraft domain fraction;
- The scheme simulates well the BOMEX, DYCOMS, ARM97 cases;
- **Future Work** will include global testing and tuning for NWP, and potentially rewriting PDF code to relax assumptions and allow closer correspondence between PDF plume and updrafts.